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No. A-3302 DATE 7/30/82

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or: Union Carbide Corporation Nuclear Division

Agreement: Project Authorization No. X-13 under Basic Agreement No. 7802

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Development of an Empirical Model of New Technology Choice for Space ating and Cooling Equipment in Commercial Buildings

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GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 7/11/83

Project Title: Development of an Empirical Model of New Technology Choice for Space Heating and Cooling Equipment in Commercial Buildings

Project No: A-3302

Project Director: Robert B. Lann

Sponsor: Union Carbide Corporation, Nuclear Division

Effective Termination Date: 6/30/83

Clearance of Accounting Charges: 6/30/83

Grant/Contract Closeout Actions Remaining:

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Development of An Empirical Model
of New Technology Choice for Space
Heating and Cooling Equipment in
Commercial Buildings

Prepared for

Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

under

Basic Agreement No. 7802

between

The Union Carbide Corporation and the Georgia
Institute of Technology

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Section I

INTRODUCTION

This report was prepared for the Energy Division of the Oak Ridge National Laboratory. It completes a two-phase study begun in April 1980, under basic agreement No. 2802. The initial phase of research involved an investigation of the market potential for coal using technologies in the commercial buildings sector. Additionally, the project involved the development of a new algorithm for forecasting the market penetration of such new technologies that could be readily incorporated into an existing commercial sector energy forecasting model. The results of the first phase endevor are contained in a report entitled, "Market Penetration of Coal Utilization Technologies in the Commercial Sector: Methodology and Foundation."

The contents of this report discusses the methodology and data development of the new fuel choice/efficiency choice algorithm that has been incorporated into a new encoded version of the commercial sector energy forecasting model. This life cycle cost based microsimulation submodule provides an improved and more flexible method for simulating the HVAC fuel and efficiency choice decision process of commercial sector firms. Section II discusses this submodule in detail. Section III discusses the steps performed in updating and expanding the original ORNL national data base necessary to run with the new code. The data development for this case is illustrative and not meant to be entirely used as is. Our objective was to show how to modify the input data base for the original ORNL model so that it conforms to the model requirements of the new code.

Section II

HVAC FUEL CHOICE/EFFICIENCY CHOICE SUBMODULE

Methodology

Heating, ventilation and air conditioning systems (HVAC) fuel choice and efficiency choice are jointly determined in a process that is structured to provide the average values for these end uses as required in the overall model based on the results of the simulated choices of many firms.

In describing this process, it is easiest to first focus on the choices modeled for an individual firm. Therefore, we first consider the decision process for a firm assuming that the energy use requirements, price expectations and discount rate have already been ascertained for that firm.

Decision Process For a Single Firm. When an HVAC equipment purchase is imminent (when old equipment is "worn out" or when a new building is designed), the decision maker must choose both a fuel type and HVAC characteristics. As demonstrated below, this is properly modeled as a joint decision.

The decision maker must select a system with the efficiency-cost combination that most closely fits the investment criterion used in that firm. The feasible combinations are described by an HVAC production relationship (i.e., the technology based relationship between equipment cost and efficiency) and represented as

$$S = A\,K^{a}\,E^{b}\,X^{c} \qquad (2\text{-}1)$$

where K = stock of HVAC equipment

E = energy use

X = other factors

$A, a, b, c,$ = parameters of the production relationship.

K and E can be related to the other variables as

$$K = A^{-1/a}\,S^{1/a}\,E^{-b/a}\,X^{-c/a} \qquad (2\text{-}2)$$

and $$E = A^{-1/b} S^{1/b} K^{-a/b} X^{-c/b} \qquad (2\text{-}3)$$

Relationships 2-2 and 2-3 indicate the level of capital and energy used for various levels of the other input factors and the level of output, assuming that the most efficient production process is used.

In an attempt to minimize life-cycle-cost of the end use system, decision makers will choose a system whose energy use-capital cost characteristics minimize the following relationship

$$LCC_T = P_{K,T} K + \sum_{t=T}^{T+n} \left[\frac{E P_{E,t} + M_t}{(1+r)^t} \right] \qquad (2\text{-}4)$$

where LCC_T = life-cycle-cost of the system in current year, T

P_k = price of capital

K = quantity of capital

E = energy use of the system

P_E = price of energy

M = maintenance cost of the system

r = discount rate applied in this investment decision

n = life of the system

Substituting 2-2 for K in equation 2-4 constrains the life-cycle-cost equation to reflect the production technology. Minimizing this new equation with respect to E gives the life-cycle-cost minimum choice of E. The corresponding K is provided by substituting the resulting value for E in equation 2-2.

This life-cycle-cost minimizing value of E is:

$$\ln E = -\frac{a}{b+a} \ln \sum_{t=T}^{T+n} \frac{P_{E,t}}{(1+r)^t} - \frac{a}{b+a} \ln \frac{a}{b} - \frac{c}{b+a} \ln X + \frac{1}{b+a} \ln S + \frac{a}{b+a} \ln P_k - \frac{1}{b+a} \ln A \qquad (2\text{-}5)$$

The relationships between the energy use of the system chosen and other variables can be summarized as

$$\frac{\partial E}{\partial P_E} < 0 \; , \; \frac{\partial E}{\partial r} > 0 \; , \; \frac{\partial E}{\partial x} < 0 \; , \; \frac{\partial E}{\partial S} > 0 \; , \; \frac{\partial E}{\partial P_K} > 0 \; ,$$

That is, increases in the discount rate, level of end use services and the price of equipment tends to increase energy use (decrease efficiency). Increases in fuel price or the level of other factors (e.g., structural efficiency) tends to reduce energy use (increase efficiency). The inverse relationship between E and K (equation (2-2)) indicates that increases in each of these variables has just the opposite effect on the level of capital used in producing the end use service.

Thus, given the discount rate (r) used by the firm in making its energy-related investments and the prices expected over the next n years ($P_{E,t}$), we may use equation 2-5 to determine the preferred energy use characteristics (i.e., efficiency) of each system under consideration. Since price expectations vary across fuels and the parameters of equation 2-1 vary to reflect fuel specific system characteristics, the efficiency choice that a firm exhibits will vary by fuel type chosen. Equation 2-5 allows us to estimate that efficiency choice for each fuel specific system as if that system were actually chosen.

The resulting energy use requirement, (E), and corresponding, (K) of each system is used in equation 2-4 to determine which fuel-specific system reflects the least life cycle cost. This minimum life cycle cost option is then chosen by the firm under consideration.

The "other" factors represented by the variable X in equation 2-2 can include lighting levels, the thermal integrity of the structure, occupancy characteristics, equipment loads, etc.

Microsimulation Approach. The process described above is actually repeated a large number of times in each forecast year, for each building type and building vintage in order to develop an average fuel choice and efficiency choice. Certain characteristics are allowed to vary from firm to firm to represent the actual variation in certain decision factors that influence the values of equation 2-4 and 2-5. Within each building type, the particular values of fuel price expectations and a discount rate occur with a frequency in our sample of establishments that corresponds to the population frequency. The use of discount rates and price expectations give the simulation its "behavioral" component since the values of these variables are determined in large part by the cost of information, access to capital markets, judgmentally based forecasts of energy market factors and other items that result in actions by commercial establishments that differ from actions expected under a perfectly competitive market scenario.

This microsimulation process utilizes prespecified population distributions. Currently, the lower, median, and upper bound distribution parameters are supplied such that 80% of the population values are between the upper and lower bounds and the median value is identical to the median parameter. A Weibull distribution was chosen because, depending on the distribution parameter values, the Weibull distribution can represent a variety of density function shapes. The Weibull cumulative distribution inverse (equation 2-6) is used to calculate each firms discount rate and price growth rate expectation. The parameters of equation 2-6 are solved using the upper and lower bounds and median.

$$X = a \left[-\ln \left(1-F(X) \right) \right]^{\frac{1}{c}} + b \tag{2-6}$$

Using $F(X)=.1$ for the lower bound, $F(X)=.5$ for the median and $F(X)=.9$ for the upper bound a, b and c are solved. The b parameter is not straight forwardly solved and must be estimated using numerical methods. The method of successive approximations is used to iterate to a value for b given lower, upper, and median values for X.

Equations 2-7 and 2-8 represent the solutions for c and a, respectively. Equation 2-9 is the relationship used to estimate b.

$$c = \frac{1.2005}{\ln\left(\frac{(X_u - b)}{(X_m - b)}\right)} \tag{2-7}$$

$$a = \exp\left[\frac{.3665}{c}\right] + \ln(X_m - b) \tag{2-8}$$

$$b_{n+1} = X_L - \frac{(X_m - b_n)^{2.5692}}{(X_u - b_n)^{1.5692}} \tag{2-9}$$

where X_m = median value

X_L = lower bound value

X_u = upper bound value

$F(X)$ = value of the cummulative distribution given X

n = iteration step number

This microsimulation approach is a very attractive way of representing fuel and efficiency choice because it incorporates the same decision variables actually used by firms in making these decisions and it permits a representation of the variation in the factors which do, in fact, vary from firm to firm. This approach offers considerable advantage over the econometric fuel-split approach used previously. The econometric representation was determined to be faulty when the model failed to forecast significant choice of electric space heating when that fuel offered significant cost advantages. Since 2-5 is a cost-based equation, that difficulty should not occur. The observed reluctance of commercial decision makers to invest in energy saving options is captured in the use of discount rate values that reflect such patterns. The interaction of end use systems such as lighting is reflected by the "other" factors in determining the energy use requirements of an HVAC system. While not pursued in our present research, this approach allows a straightforward incorporation of new technologies if one provides the energy-capital cost technology curve and the cost-equivalent disincentive generated by uncertainty of the new technology. The obvious new issues raised with this approach relates to the estimation of the population distributions of fuel price expectations and discount rates. This topic is the focus of the next section.

Data Development

To calculate the distribution of discount rates and price expectations as discussed in the previous section the microsimulation approach is employed. To generate the numbers using equation 2-6 a set of uniform probabilities, one set of five (three fuels and two discount rates (Public vs. Private sector), for each observation are chosen using a computerized random number generator in the interval 0,1. The population distribution parameters, X_L, X_m, X_u are derived as follows.

On the basis of a review of approximately two hundred case studies compiled from past issues of Energy Users News, we have concluded that commercial firms are reluctant to invest in energy saving investments. That is, unexpectedly strict investment criterion are used to evaluate energy-related investments. This finding is consistent with the conventional wisdom and "rules-of-thumb" often reported in this area. We believe that such behavior is, in fact, economically rational and can be explained by several factors including, uncertainty related to cost savings (in part from uncertainty over the technology, in part from other factors such as uncertainty of future weather trends which help determine cost savings), fuel price, and resource competition with other goals of the organization such as enhancement of market shares through advertising expenditures or product upgrading.

In any case, high discount rates (i.e., short payback periods) are without question applied in energy related investment decisions. We have specified the upper, median, and lower bound parameters of 25%, 50%, and 75% for the discount rate parameters. That is, we assume that 80% of all commercial establishments use discount rates between 25% and 75% with a corresponding required payback period of from 5 and 2.3 years.

To estimate the distribution of expected prices we used price expectations published by Energy Users News from their survey of energy users. The number of panelists ranged from 64 to 70 in January, February, March, and April 1982 issues which were used to determine the appropriate parameters for this application. Energy Users News publishes the median estimate and the highest and lowest estimate. Oftentimes the two highest (or two lowest) estimates are published if the highest (or lowest) estimate appears to be an outlier. We used these data to develop an estimate of the variance of the price expectations around the median. The resulting upper and lower bound parameters showed an approximately 80% coverage for rates of electricity price increase that varied from -10.33 to 6.33% around the median; from -11.07% to 6.33% for gas; and from -8.33% to +8.33% around the reported oil prices median expectation. Thus, on the basis of these data, if the median electricity price expectations were 12%, we can assume that 80% of the population expects rates of increase that range from 1.67% to 18.33%. In our forecasts, we assume that commercial decision makers are accurate forecasters of price increases on average, but that individual forecasts vary according to the information developed from Energy Users News. This assumption allows us to use exogenously supplied price forecasts to represent the average price in any forecast year.

Incorporating these values into the model where the median expectation is equal to the exogenously supplied price forecast, the bounds are input as:

	Lower	Median	Upper
Electricity	.8967	1.00	1.0633
Natural Gas	.8833	1.00	1.0633
Fuel Oil	.9167	1.00	1.0833

Additional Data Requirements. The DOE 2.1 heat load model is used to develop the annual HVAC energy use requirements (E) used in estimation of equation 2-3. DOE 2.1 inputs require a vast array of information on building shell characteristics, equipment characteristics, internal loads and schedules, and weather. Based on the HVAC system modeled and the shell characteristics, cost estimates in dollars per square foot can be calculated for each run. Lighting level is input to DOE 2.1 and, therefore, predetermined. These data are generated in a controlled experiment by running DOE 2.1 using all of the sixteen possible combinations of the four input factors (see equation 2-10 below) with two specifications; one for high energy use and one for low energy use.

Three prototype building specifications were modeled for DOE 2.1 consisting of a 40,500 sq. ft. office, a 40,000 sq. ft. school and a 180,000 sq. ft. hospital. Tables 2-1 through 2-3 contain the specifications for each, respectively.

For this illustrative example data developed from a previous application of the submodule is used. In that application, each building prototype was run with weather for two locations; Portland, Oregon and Yakima, Washington. Weather tapes from the National Oceanic and Atmospheric Administration (NOAA) were used for weather information corresponding to a typical meteorological year (TMY). These TMY tapes use actual months selected from various years in which the month selected is representative of 'typical' weather. That is, weather data for say January could be from 1960 and February weather could be from an entirely different year.

Parameter Estimation

As stated above, there are sixteen combinations to consider for running a regression to estimate the parameters in equation 2-3. Our empirical specification identifies two components of "other" factors; structure capital (thermal integrity) and lighting level. Equation 2-10 illustrates this estimating equation.

$$\ln E = a_0 + a_1 \ln KE + a_2 \ln KS + a_3 \ln S + a_4 \ln L \qquad (2\text{-}10)$$

where E = HVAC Energy use per sq. ft.

KE = HVAC equipment cost per sq. ft.

KS = Cost per sq. ft. of the components of structure that change from high to low energy use settings; windows, walls, and roof

Table 2-1

OFFICE BUILDING DOE 2.1 SPECIFICATIONS

al:
Area = 40,500 square feet
Number of stories = 3
Yearly Schedule = 12 months

	High Energy Use	Low Energy Use
s:		
essed Flourescent ceiling	3.5 watts/sq. ft.	2.5 watts/sq. ft.
Equipment:		
r Delivery	Multizone with constant air-flow to 5 zones	Same with addition of rotary heat exchanges
ant	Electric hot water boiler Hermetic reciprocating chiller and cooling tower	Electric hot water boiler Double bundle chiller
ture:		
lls	4" face brick 1" air space 8" concrete block 1/2" gypsum board	4" face brick 1" air space 8" concrete block 1/2" insulation, R-2 1/2" gypsum board
of	1/2" stone 3/8" felt 1" insulation, R-3 Metal deck Air space Suspended Acoustic Tile	1/2" stone 3/8" felt 2 1/2" insulation, R-7 Metal deck Air space Suspended Acoustic tile
ndows	30% of wall area Single pane	30% of wall area Triple glazing
ting:		
ermostat settings	7:00 am. - 6:00 pm. on workdays Cooling-70° Heating-75° Set back 6° at all other times	7:00 am. - 6:00 pm. on workdays Cooling-76° Heating-68° Set back 6° at all other times
tside air	20 CFM/person	10 CFM/person

Table 2-2

HOSPITAL BUILDING DOE 2.1 SPECIFICATIONS

al:
Area = 180,000 square feet
Number of stories = 4
Yearly Schedule = 12 months

	High Energy Use	Low Energy Use
s:		
cessed Flourescent ceiling	3.5 watts/sq. ft. in core 2.25 watts/sq. ft. in perimeter	2.5 watts/sq. ft. in core 1.75 watts/sq. ft. in perimeter
Equipment:		
r Delivery	Four pipe fan coil in each patient room Constant air volume in treatment rooms	Same with addition of a noncontact heat exchanger
ant	Electric hot water boiler Centrifugal chiller and cooling tower	Electric hot water boiler Double bundle chiller
ture:		
lls	4" face brick 1" air space 8" concrete block 1/2" gypsum board	4" face brick 1" air space 8" concrete block 1/2" insulation, R-2 1/2" gypsum board
of	1/2" stone 3/8" felt 1" insulation, R-3 Metal deck Air space Suspended Acoustic Tile	1/2" stone 3/8" felt 2 1/2" insulation, R-7 Metal deck Air space Suspended Acoustic tile
ndows	20% of wall area Single pane	20% of wall area Triple glazing
ting:		
ermostat settings	7:00 am. - 6:00 pm. on workdays Cooling-70^{o} Heating-75^{o} Set back 6^{o} at all other times	7:00 am. - 6:00 pm. on workdays Cooling-76^{o} Heating-68^{o} Set back 6^{o} at all other times
tside air	3.5 Airchanges/hour in core 2.0 Airchanges/hour in perimeter	3.0 Airchanges/hour in core 1.8 Airchanges/hour in perimeter

Table 2-3

SCHOOL BUILDING DOE 2.1 SPECIFICATIONS

al:
Area = 40,000 square feet
Number of stories = 1
Yearly Schedule = 9 months

	High Energy Use	Low Energy Use
s:		
essed Flourescent ceiling	3.0 watts/sq. ft.	2.0 watts/sq. ft.
Equipment:		
r Delivery	Four pipe fan coil in classrooms, office, cafeteria	Same
ant	Electric hot water boiler Hermetic reciprocating chiller and cooling tower	Electric hot water boiler Double bundle chiller
ture:		
lls	4" face brick 1" air space 8" concrete block 1/2" gypsum board	4" face brick 1" air space 8" concrete block 1/2" insulation, R-2 1/2" gypsum board
of	1/2" stone 3/8" felt 1" insulation, R-3 Metal deck Air space Suspended Acoustic Tile	1/2" stone 3/8" felt 2 1/2" insulation, R-7 Metal deck Air space Suspended Acoustic tile
ndows	15% of wall area Single pane	15% of wall area Triple glazing
ting:		
ermostat settings	7:00 am. - 6:00 pm. on workdays Cooling-70° Heating-75° Set back 6° at all other times	7:00 am. - 6:00 pm. on workdays Cooling-76° Heating-68° Set back 6° at all other times
tside air	15 CFM/person	12 CFM/person

Table 2-4

HEAT PUMP SPECIFICATIONS

Office:

Individual heat pumps serving each zone with the outside coil a water-to-refrigerant heat exchanger connected to a common water loop which is normally at a temperature between the conditioned space and outside, thus increasing efficiency. Electric hot water boiler and cooling tower backup.

Hospital:

Not modeled.

School:

Individual through-the-wall air-to-air heat pump in each room. Electric hot water boiler and cooling tower backup.

S = level of end use services, arbitrarily set at 2 for high energy use and 1 for low energy use

L = lighting level in watts per sq. ft.

Table 2-5 illustrates the way in which the high/low settings are arranged for running the sixteen alternative specifications with DOE 2.1 and setting up the regression. Alternatively, to reduce the expenditures of running DOE 2.1, and without severely compromising the results, ten runs could be used for estimation. These include all cases where each of the four variables are changed one at a time while holding all others at first their high settings and then at their low settings. In Table 2-5, these would be cases 1, 2, 4, 5, 7, 8, 9, 12, 14, and 16. This reduces the number of runs from 32 (16 x 2 weather zones) to 20 (10 x 2 weather zones) for each building. For three prototypes this reduces the runs from 96 down to 60.

Table 2-5

EXPERIMENTAL DESIGN FOR DOE 2.1 RUNS

Energy Use Characterizations

Case #	Structure	Lights	Service	Equipment
1	H	H	H	H
2	H	L	H	H
3	L	H	L	H
4	L	H	L	L
5	L	H	H	H
6	L	H	H	L
7	L	L	L	H
8	L	L	L	L
9	L	L	H	L
10	L	L	H	H
11	H	L	H	L
12	H	H	H	L
13	H	H	L	L
14	H	L	L	L
15	H	L	L	H
16	H	H	L	H

Four HVAC systems are specified for analysis and use in the fuel share module. These are electric resistance, electric heat pump (see Table 2-4), a natural gas heating system, and an oil heating system. A set of coefficients is required for each of the four systems both with and without air conditioning. Ideally, DOE 2.1 should be run without an air conditioning system to derive the data for estimating this specification. Alternatively, the air conditioning annual load can be subtracted from HVAC annual use and the KE variable adjusted accordingly to set up the data to estimate systems without air conditioning. The efficacy of this alternative must be determined by weighing the costs of additional runs against the importance of non-air conditioned space in commercial buildings. Since it is widely accepted that almost all new floor space in the commercial sector has for years been built with air conditioning, this trade off is probably acceptable.

As Tables 2-1 to 2-3 indicate, an electric heating system was specified for each run. To derive data necessary for the natural gas systems, an efficiency factor is used to adjust the HVAC annual loads and KE is adjusted accordingly. The electric heating load is multiplied by 1.27 to derive the natural gas numbers. Coefficient estimates for the natural gas system are then used for the oil system. In the model, different base year capital cost figures are used for gas and oil but the responsiveness of HVAC efficiency choice to the explanatory variables is assumed to be the same for both.

For this project, we opted to reduce the runs to the minimum five per building per weather zone. The coefficients of equation 2-10 shown in Table 2-6 can be estimated by simply looking at two cases for each coefficient; one with the high setting and one with the low where all other variables stay at their high settings. The resulting change in E is a consequence then of the change in that one variable. Taking the ratio of the percentage change in E to the percentage change in the explanatory variable will produce an estimate of that coefficient.

For example, using data from Appendix C, Office-Portland, the coefficient for KE (-2.24 in Table 2.6) is calculated by taking the ratio of the percentage change in HVAC going from case HHHH to HHHL, to the percentage change in costs:

$$\% \text{ HVAC} = \frac{(4{,}713 - 10{,}698)}{10{,}698} = -.5595$$

$$\% \text{ Costs} = \frac{(\$6.50 - \$5.20)}{\$5.20} = .25$$

$$\text{KE} = \frac{-.5595}{.25} = -2.24$$

Our decision to estimate the coefficients in this manner was based primarily on budget constraints. The costs associated with running DOE 2.1, producing the data series for estimation and the estimation phase were judged to be beyond the limits of our budget for these tasks. The exploratory nature of this analysis and our recognition of other important issues which are involved but could not be addressed because of data limitations as well as budget constraints led us to this decision. Once better survey information is compiled on a large sample of buildings in each building type, e.g., office, retail, hospital, grocery, restaurants, etc., a better determination of what is a "typical" structure in both a physical and operational sense can be sought. This will greatly improve confidence in the results by virtue of improving the representativeness of the prototype buildings.

The heat load results and cost data are contained in Appendix A.

Table 2-6

Coefficient Estimates for Equation 2-5

	Office ER	Office HP	Office FF	Hospital ER	Hospital HP	Hospital FF	School ER	School HP	School FF
Portland									
With AC									
KE	-2.24	-2.24	-1.40	-2.58	-2.58	-1.65	-2.00	-2.00	-1.50
KS	-.170	-.170	-.150	-.210	-.210	-.150	-.040	-.040	-.040
L	.300	.300	.350	-.100	-.100	.100	-.040	-.040	.010
S	.88	.88	.33	.02	.02	.09	.11	.11	.12
Without AC									
KE	-2.77	-2.77	-2.09	-2.77	-2.77	-2.09	-2.00	-2.00	-1.50
KS	-.220	-.220	-.190	-.220	-.220	-.190	-.040	-.040	-.040
L	0.0	0.0	0.0	0.0	0.0	0.0	-.05	-.05	0.0
S	.40	.40	.37	.40	.40	.37	.11	.11	.12
Yakima									
With AC									
KE	-2.41	-2.41	-1.56	-3.32	-3.32	-2.35	-2.00	-2.00	-2.00
KS	-.180	-.180	-.180	-.110	-.110	-.090	-.050	-.050	-.040
L	0.0	0.0	.35	-.05	-.05	.09	-.04	-.04	0.0
S	.39	.39	.35	.05	.05	.10	.10	.10	.11
Without AC									
KE	-2.91	-2.91	-2.23	-2.91	-2.91	-2.23	-2.00	-2.00	-2.00
KS	-.190	-.190	-.180	-.190	-.190	-.190	-.050	-.050	-.050
L	0.0	0.0	0.0	0.0	0.0	0.0	-.04	-.04	0.0
S	.41	.41	.38	.41	.41	.38	.10	.10	.11

ER = Electric Resistance, HP = Heat Pump, FF = Fossil Fuel (Gas & Oil)

Subroutine Structure

This section will describe how the fuel/efficiency choice methodology is implemented into the overall commercial end use model code.

The submodule has been divided into two subroutines; DISTR and FSHAR. The subroutine DISTR is called by MAIN at the beginning of execution and a series of calculations are performed to set up values for arrays which are either constant over time or not dependent on other variables which are redefined as execution proceeds. The main function of DISTR is to set up the price expectation and discount rate distributions for the sample of firms whose fuel and efficiency choices will be simulated over the forecast period in the second section. Additionally, this first section will calibrate the encoded form of equation 2-5 by calculating a constant that ensures an initial value of E equal to the base year value input.

Subroutine DISTR

Price and Discount Rate Distribution: The discount rate distributions (EDR) are calculated first followed by the price expectation distributions (EPR) for each fuel. The series of calculations used to calculate the values for each array are identical in logic. In the section on methodology, equations 2-6 thru 2-9 were presented. These equations are encoded into a series of calculations beginning with the iterative solution for, b (ED), using equation 2-9. Once, b, is determined, the code calculates a value for, c (CD), using equation 2-7. The value for, c, is then used to calculate, a (DAL), using equation 2-8.

Equation 2-6 is encoded in a loop which calculates a discount rate for each firm using the previously calculated values for a, b and c. The index, ID, in the code takes on values of 1 and 2 and is used to index EDR for storage of two discount rates per firm. The two discount rates can represent private and public sector values, respectively. Public institutions such as schools may use a different discount rate than private sector firms given their different pay back period criteria and availability to financing. The values of X_L, X_m, and X_u are used to differentiate between the two and the variable IRB is used to select one or the other for each building type.

The price expectation distribution array EPR follows the same series of calculations with variable names changed to distinguish them from the previous discount rate calculations. ED becomes EP, CD becomes CP, and DAL becomes PAL.

Present Value Calculation: Once EDP and EPR are calculated the code performs the present value calculation of fuel costs for each fuel type and firm in the sample for all simulation years. The variable SUMPV stores these values for later use in the second section. RHT contains the number of years input from variable NREPL corresponding to the lifetime of HVAC systems.

Calibration of Equation 2-5: Using the base year value of PREVAL, the base year space heating EUI's (electric is split into electric resistance and heat pump and stored in SHEBS as well as the gas and oil EUI's) and fuel prices in the base year, the dollar value of the present discounted value of operating costs is calculated. PVHT, PVAC and PVVT store the present value calculations for heating, cooling, and ventilation, respectively.

Going back to equation 2-5, and noting that E is normalized to 1.0 in the base year for use in the model coding, it is clear that for E to average out to 1.0 in the base year the constant needs to be equal to the reciprical of the base year present value calculation. The other terms in the equation; lighting EUI, thermal integrity and utilization are also all normalized to 1.0 in the base year for use in the model code. Therefore, the product of the constant and the present value term in the equation must average to 1.0 over all firms. The constant is then stored in TCC (I, 1, L).

Subroutine FSHAR

This subroutine is called from subroutine UPDAT twice each year of the simulation; once for replacement systems and once for new construction. The other floor space stock vintages replacing HVAC systems acquire the same results calculated by FSHAR for the replacement system on the first pass through.

The comment statement that begins with IAC = 1 starts the loop that calculates the efficiency choice, the capital cost corresponding to the efficiency choice and the resulting life cycle cost (LCC). These calculations are run for the sample of firms for each of the four systems with and without air conditioning. In effect, there are two segments of the population which are run through the calculations.

The estimated parameters of equation 2-10, are transformed to calculate the parameters of equation 2-5, which is the life cycle cost minimizing relationship for efficiency choice, E. In the code these transformed parameters are B1, B2, B3, and B4. The capital cost equation (2-2) parameters are also calculated from the estimated parameters of equation 2-10. In the code these transformed parameters are C1, C2, C3, and CDEN.

Since the model requires separate heating, cooling, and ventilation EUI's the HVAC EUI is split into its components after efficiency is calculated. Estimates of how much of an efficiency gain could be attributed to each end use on average were calculated from the heat load runs. The variables HVSP1 and HVSP2 contain these estimates.

Once LCC is calculated for each system for a particular firm, the minimum is found and the system index and HVAC EUIS are stored away until all firms have been run through. Each choice is weighted by a factor corresponding to the segment (with/without AC) being simulated. The fuel shares are then calculated from the accumulated number of weighted choices for each fuel type (electric resistance and heat pump are combined into electric) after both segments have been run through. The average heating, cooling, and ventilation EUIs are calculated from the chosen systems of each fuel type.

Section III

DATA MODIFICATIONS TO ORNL NATIONAL VERSION

Floor Space:

Recent analysis has shown previous estimates of national floor space to be low. To incorporate the latest estimates of floor space, two issues had to be addressed. The first was the reorganization of building types contained in the original ORNL model to attain consistency with the new model. The second was a recalibration of the equations and historical additions series to conform to the latest estimates. The reorganization of building types was accomplished as follows, and a mapping of building types is given in Table 3-1.:

1. Offices: The ORNL model contained two office categories, i.e., offices and public buildings. These two were merged to get the new office category. Because the old office category dominated, the forecasting equation used for offices was retained for predictive purposes.

2. Restaurants: The old ORNL model did not contain this building type. It was disaggregated from the Retail/Wholesale category by taking the proportion of restaurant floor space to the total of restaurant, grocery, and retail in the new estimates and multiplying this by the ORNL Retail/Wholesale floor space.

3. Retail: This building type was estimated analogously to restaurants described above except that the proportion used was retail to total Retail/Wholesale.

4. Grocery: This represents the third building type which was disaggregated from the old Retail/Wholesale category by taking its proportion to the total analogously to restaurants and retail.

5. Warehouse: This building type is the same in both models. No changes were, therefore, necessary at this stage.

6. Elementary/Secondary Schools: This building type was included along with colleges in a total educational building category in the old model. It was, therefore, necessary to disaggregate it from the total. This was done using the proportion of Elementary/Secondary floor space to the total of that and College/Trade School floor space, and

multiplying it by the Educational Buildings floor space in the old model.

7. College/Trade Schools: This was calculated as the remaining portion of floor space after Elementary/Secondary Schools were disaggregated as described above.

8. Health: No reorganization was necessary for this building type as the old and new definitions were consistent.

9. Hotel/Motel: No reorganization was necessary for this building type as the old and new definitions were consistent.

10. Miscellaneous: The new miscellaneous building type was estimated by summing the old miscellaneous building type with religious services and auto repair. Because the old miscellaneous category dominated the floor space, its predictive equation was used for forecasting purposes.

The second step in modifying the floor space data was to incorporate the newer estimates of national floor space. Two separate procedures were necessary to do this. First, the proportion of the old estimate to the new estimate was calculated for each building type for the year 1979, i.e., the year of the new estimate of stock. This proportion was then multiplied by each year of additions and the 1924 stock estimate for each building type. This implicitly assumes that the underestimation of floor space is distributed homogenously over time. The factors used to correct for the new floor space estimates are given on Table 3-2. The second step used the 1979 new estimates and the new estimates of 1980 additions to estimate the 1980 stock. The equation for forecasting each building type was calibrated to this estimate through modification of the constant term. These constraints are given on Table 3-3. No reestimation of coefficients was done.

Fuel Shares:

The three end uses whose fuel shares are relevant are heating, water heating, and cooling. The aggregate heating fuel shares given in the ORNL model were 5%, 39%, 53%, and 3% for electricity, gas, oil, and other, respectively. For the new model run, the 'other' was parcelled out to gas and oil (1% and 2%, respectively) to result in an

Table 3-1

Mapping of Original ORNL Building Types To New Building Types

Old	New
Retail/Wholesale	Retail Restaurants Grocery
Offices Public Buildings	Offices
Warehouse	Warehouse
Educational Services	Elementary/Secondary School College/Trade School
Health	Health
Hotel/Motel	Hotel/Motel
Auto Repair Religious Services Miscellaneous	Miscellaneous

Table 3-2

Multiplicative Factors Used To Correct For
Latest 1979 Floor Space Estmates

Building Type	Factor
Offices	1.356
Restaurant	1.375
Grocery	1.375
Retail	1.375
Warehouse	1.901
Elementary/Secondary School	.977
College/Trade School	.977
Health	.900
Hotel/Motel	.929
Miscellaneous	1.575

Table 3-3

Calculated Floor Space Predictive Equation
Constant Terms To Calibrate to 1980 Stock

Building Type	Coefficient
Offices	1.6183
Restaurant	.4866
Grocery	.9573
Retail	3.8278
Warehouse	1.5389
Elementary/Secondary School	8.8651
College/Trade School	3.4658
Health	2.9511
Hotel/Motel	1.6635
Miscellaneous	9.0411

initial fuel share split for heating for the base year (1970) of 5% electricity, 40% gas, and 55% oil for all building types.

Because gas cooling is not a technology included in present models, the gas fuel share in cooling was changed to zero. The electric cooling fuel share remained at 49.5%. The water heating fuel shares of 8%, 39%, and 53% for electricity, gas, and oil, respectively, was retained for all building types as per the ORNL model data.

Interpolations:

The fuel price data and the two exogenous variables in the floor space forecasting equation (income and population) were not provided on an annual basis. The interviening years were interpolated using average annual rates of change between the ranges provided.

Capital Cost Data:

The new fuel share subroutines utilize greatly expanded technology curves for the fuel choice and efficiency forecasts. The capital cost data used in describing these technologies was developed from the "Means Construction Cost" data for the Pacific northwest modeling effort. These data are averages over large cities in the U.S. and should, therefore, be adequate as an illustrative example of the new model's operation. The capital cost data contained in the ORNL 1970 base national model were not used.

Base Year EUI's:

A program has been developed which calibrates the base year EUI's, and fuel shares to the floor space and actual energy used in the base year. The program iterates to required EUIs and space heating fuel shares given an error band of ±1% on electricity sales, and a user determined band on the ratio of natural gas space heating EUI to electric space heating EUI.

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*References used in data development are designated with an asterisk following the date of publication.

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APPENDIX A

Heat Load Simulation Results

Office - Portland

Case	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHH	6,975	2,008	1,715	1,178	252	12,128	0	0	0	0
HHHL	949	2,049	1,715	1,178	252	6,143	0	0	.55	.75
HHLH	3,934	1,503	1,243	1,178	252	8,110	0	0	0	-.44
HLHH	6,514	1,718	1,510	841	252	10,835	0	-.665	0	-.26
LHHH	*									
LLLL	350	1,177	901	841	252	3,521	1.58	-.665	.55	-.25
LLLH	2,907	1,089	901	841	252	5,990	1.58	-.665	0	-.80
LLHL	888	1,497	1,246	891	252	4,724	1.58	-.665	.55	.11
LHLL	235	1,431	1,050	1,178	252	4,146	1.58	0	.55	-.07
HLLL	501	1,312	1,094	841	252	4,000	0	-.665	.55	.04
					Base Cost:		1.63	2.20		5.20

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing) (KE)
H - High energy use
L - Low energy use

Hospital - Portland

	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
Case	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHH	20,375	1,520	5,365	11,444	6,016	44,720	0	0	0	0
HHHL	12,136	2,065	5,263	11,444	6,016	36,924	0	0	.93	.28
HHLH	21,771	1,123	3,917	11,444	6,016	44,271	0	0	0	-.26
HLHH	22,107	1,168	4,680	8,454	6,016	42,425	0	-.49	0	-.07
LHHH	*									
LLLL	10,468	1,286	3,130	8,454	6,016	29,354	.64	-.49	.93	-.31
LLLH	21,393	909	3,237	8,454	6,016	40,009	.64	-.49	0	-.47
LLHL	10,084	1,591	4,313	8,454	6,016	30,458	.64	-.49	93	0
LHLL	10,204	1,719	3,647	11,444	6,016	33,030	.64	0	.93	-.15
HLLL	14,070	1,172	3,352	8,454	6,016	33,064	0	-.49	.93	.11
					Base Cost:		.67	1.84		10.9

*Case not run

S = Structure
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O = Operation
E = Equipment

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LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

School - Portland

Case	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHH	7,016	71	638	527	43	8,295	0	0	0	0
HHHL	6,833	96	638	527	43	8,137	0	0	0	.70
HHLH	6,305	45	515	527	43	7,435	0	0	0	-.09
HLHH	7,185	50	580	351	43	8,209	0	-.625	0	-.07
LHHH	6,706	79	618	527	43	7,973	.88	0	0	-.07
LLLL	*									
LLLH	*									
LLHL	*									
LHLL	*									
HLLL	*									
					Base Cost:		.84	1.20	4.60	

*Case not run

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O = Operation
E = Equipment

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LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

Office - Yakima

	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
Case	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHH	7,362	1,843	1,672	1,178	253	12,308	0	0	0	0
HHHL	1,695	1,862	1,672	1,178	253	6,660	0	0	.55	.60
HHLH	4,108	1,338	1,209	1,178	253	8,086	0	0	0	-.48
HLHH	6,919	1,551	1,460	841	253	11,024	0	-.665	0	-.26
LHHH	5,944	1,560	1,388	1,178	253	10,323	1.58	0	0	-.46
LLLL	*									
LLLH	*									
LLHL	*									
LHLL	*									
HLLL	*									
					Base Cost:		1.56	2.20	5.34	

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

Hospital - Yakima

	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
Case	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHH	30,089	1,585	5,191	11,444	6,016	54,325	0	0	0	0
HHHL	17,901	2,300	5,020	11,444	6,016	42,681	0	0	.93	.13
HHLH	30,055	1,173	3,794	11,444	6,016	52,482	0	0	0	-.32
HLHH	31,595	1,279	4,503	8,454	6,016	51,847	0	-.49	0	-.11
LHHH	26,703	1,547	4,870	11,444	6,016	50,580	.64	0	0	-.17
LLLL	*									
LLLH	*									
LLHL	*									
LHLL	*									
HLLL	*									
					Base Cost:		.69	1.84	11.14	

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

School - Yakima

Case	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHH	8,234	71	644	527	43	9,519	0	0	0	0
HHHL	8,038	91	644	527	43	9,343	0	0	0	.60
HHLH	7,444	49	532	527	43	8,595	0	0	0	-.08
HLHH	8,415	52	589	351	43	9,450	0	-.62	0	-.07
LHHH	7,835	77	621	527	43	9,103	.88	0	0	-.10
LLLL	*									
LLLH	*									
LLHL	*									
LHLL	*									
HLLL	*									
						Base Cost:	.84	1.90	5.03	

*Case not run

S = Structure
L = Lighting
O = Operation
E = Equipment

STR - Change in structure components cost (KS)
LGT - Change in lighting costs (L)
REC - Change in cost for heat recovery (KE)
EQUIP - Change in HVAC cost (sizing)
H - High energy use
L - Low energy use

Office - Heat Pump - Portland

	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
Case	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHHP	2,277	538	748	1,178	252	4,493	0	0	0	0
HLHHP	2,490	412	659	840	252	4,653	0	-.625	0	.11
HHLHP	1,231	222	533	1,178	252	3,416	0	0	0	.78
LHHHP	1,680	520	630	1,178	252	4,260	1.49	0	0	.96

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use

School - Heat Pump - Portland

	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
Case	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHHP	4,673	99	567	527	43	5,909	0	0	0	0
HLHHP	4,708	76	512	351	43	5,690	0	-.62	0	-.22
HHLHP	3,945	85	448	527	43	5,048	0	0	0	-.53
LHHHP	4,559	105	549	527	43	5,783	.88	0	0	-.07

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery (KE)

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use

Office - Heat Pump - Yakima

	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
Case	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHHP	2,862	503	733	1,177	252	5,527	0	0	0	0
HLHHP	3,098	394	642	840	252	5,226	0	-.625	0	-.53
HHLHP	1,628	478	522	1,177	252	4,057	0	0	0	-.69
LHHHP	2,119	445	606	1,177	252	4,599	1.49	0	0	-.51

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery (KE)

EQUIP - Change in HVAC cost (sizing)

H - High energy use

L - Low energy use

School - Heat Pump - Yakima

Case	ENERGY (MMBtu)						COSTS (Change $/FT**2)			
	HEAT	COOL	AUX	LIGHTS	EQUIP	TOTAL	STR	LGT	REC	EQUIP
S L O E										
HHHHP	4,259	113	545	527	43	5,487	0	0	0	0
HLHHP	4,297	90	492	351	43	5,273	0	-.62	0	-.15
HHLHP	3,719	98	434	527	43	4,821	0	0	0	-.55
LHHHP	4,158	117	527	527	43	5,373	.88	0	0	0

S = Structure

L = Lighting

O = Operation

E = Equipment

STR - Change in structure components cost (KS)

LGT - Change in lighting costs (L)

REC - Change in cost for heat recovery (KE)

EQUIP - Change in HVAC cost (sizing) (KE)

H - High energy use

L - Low energy use